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J. W. H. Wang

*Iowa State University*

R. L. Handy

*Iowa State University*

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## Comparison of Various Commercial Hydrated Lime for Reducing Soil Plasticity<sup>1</sup>

J. W. H. WANG AND R. L. HANDY<sup>2</sup>

*Abstract.* Atterberg limits tests were performed on mixtures of gumbotil soil and the various chief chemical compounds found in hydrated limes. The results were then checked with commercial hydrated limes of varying chemical compositions.

Results indicate that among the major constituents of hydrated limes  $\text{Ca}(\text{OH})_2$  is most effective in reducing soil plasticity.  $\text{MgO}$  shows a moderate effect, but  $\text{Mg}(\text{OH})_2$  and  $\text{CaCO}_3$  show practically no effect.

There is, however, practically no difference between different types or between the same type of commercial hydrated limes for the reduction of soil plasticity. The choice of lime for soil-lime stabilization should, therefore, be dictated by the relative price and pozzolanic strength characteristics of the lime.

Hydrated lime, usually calcium hydroxide, mixed with wet clay soils quickly reduces their plasticity, i.e., brings about a change from sticky to crumbly texture. Such lime modification is useful for "drying up" mud holes for support of construction equipment, or for pre-treatment of clays to aid later pulveriza-

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<sup>2</sup> Research Assistant and Professor of Civil Engineering, Iowa State University, respectively.

tion for stabilized roads. When the level of treatment exceeds the amount needed for modification of clays, additional strength is gained from pozzolanic reactions. The mechanisms involved in lime modification and cementation of clayey soils have been thoroughly studied (1, 2, 3, 4, 5).

Hydrated limes are commonly used in soil-lime work because they are easily handled in powder form. In recent soil-lime stabilization research, hydrated limes have varied in effectiveness in production of strength, depending upon the type of lime (6, 7). The variation in strength production brought up the question as to whether limes would also show variations in modifying soil plasticity.

The effects of the major components in lime on the plasticity properties of a soil were therefore studied. The results were checked with those of commercially produced limes of varying chemical compositions. Atterberg limit tests were the bases used to evaluate the relative effectiveness of the various additives for the reduction of soil plasticity.

#### MATERIALS

Soil. A highly plastic gumbotil soil was used for the liquid limit and plastic limit tests. This soil, a paleo B horizon developed in Kansan stage till, contains about 60% montmorillonitic clay. It is one of the most difficult soils to work with in the field.

A field description and physical and chemical properties of the soil are given in reference 7.

Limes. High-calcium limes are produced from calcareous materials (generally from limestone, but also from chalk and oyster shells) containing 95 to 99% calcium carbonate. Dolomitic limes are produced from dolomite, a type of limestone containing from 30 to 45% magnesium carbonate and the rest calcium carbonate.

The chemical composition of each lime used in this investigation is given in Table 1.

#### METHODS OF INVESTIGATION

ASTM Specification D 423-59 and D 424-59, for liquid limit and plastic limit respectively, were followed. Also after the soil, additive, and distilled water were mixed together, the mix was scraped into a porcelain pan, covered, and stored in a near 100% humidity room for one hour to allow for uniform wetting of the sample. After being seasoned, enough of the mixture was placed in an evaporating dish for four liquid limit tests.

A sample weighing about 10 grams was taken from the mixture prepared for the liquid limit tests. Four plastic limits were rolled

Table 1. Properties of limes<sup>a</sup>

Lime No. <sup>b</sup>	Chemical Constituents (% by wt.)					Loss on Sieve Analysis	
	CaO	Ca(OH) <sub>2</sub>	MgO	SiO <sub>2</sub>	R <sub>2</sub> O <sub>3</sub> <sup>c</sup>	Ignition	(% Passing # 325)
D2	47.13	61.86	34.49	2.20	1.00	16.08	65.80
D3	48.30	63.80	33.20	0.60	1.10	16.80	99.24
D5	47.60	62.86	32.00	0.81	0.56	19.03	96.80
D9	45.36	59.92	36.29	0.40	0.63	20.89	
D12	47.00	62.09	33.00	1.00	0.70	17.00	96.20
C1	72.00—	95.11—	0.40—	1.00—	0.10—	23.50—	95.00—
	75.00	99.08	1.40	1.60	0.40	24.50	96.00
C3	74.18	93.74	0.09	0.45	0.37		99.25
C8	73.94	97.68	0.64	0.69	0.59	24.05	97.00

<sup>a</sup> Data supplied by respective lime manufacturers.<sup>b</sup> D = dolomitic monohydrate lime; C = high-calcium hydrated lime.<sup>c</sup> R<sub>2</sub>O<sub>3</sub> = Al<sub>2</sub>O<sub>3</sub> + Fe<sub>2</sub>O<sub>3</sub>.

for each mixture studied. The plastic limits of the mix at each percentage additive were determined as the average of the moisture contents of the four threads rolled.

#### RESULTS AND DISCUSSION

Effects of the Major Components Found in Hydrated Limes. The results of the plasticity tests on the mixtures of the natural soil and the major components found in hydrated limes are shown in Table 2.

Table 2. Results of plasticity tests on gumbotil with chemical reagents.

Kind	Chemical Amount, %	Liquid Limit, %	Plastic Limit, %	Plasticity Index	De-crease in Plasticity Index	Increase in Plastic Limit	pH
No Additives		68	23	45			6.7
Ca(OH) <sub>2</sub>	2	60	43	17	28	20	11.8
	8	55	45	10	35	22	12.2
MgO	2	63	30	33	12	7	10.5
	8	68	39	29	16	16	10.7
Mg(OH) <sub>2</sub>	2	70	28	42	3	5	9.8
	8	70	31	39	6	8	10.0
CaCO <sub>3</sub>	2	61	26	35	10	3	7.4
	8	59	25	34	11	2	7.4

It is clearly seen that the effect of all the chemical constituents except calcium carbonate is mainly one of increasing the plastic limit, thus lowering the plasticity index. However, plasticity indices of the calcium carbonate-treated gumbotil are reduced chiefly due to the lowering of liquid limits, while the plastic limits are practically unchanged.

It is appropriate to discuss here the significance of those limits. In general, the liquid limit of a clay is defined as the water content above which the clay in the remolded state acts as a fluid and below which it acts as a plastic substance. It is essentially a type of shear test giving the water content of any

clay when its strength has been reduced to some very small but very finite quantity. The plastic limit, on the other hand, is defined as the water content below which the clay has ceased to behave as a plastic material and becomes friable or crumbly. The difference between the liquid and plastic limits is the range of water content over which the remolded clay behaves as a plastic material, and is referred to as the plasticity index.

If the reduction of plasticity index results from an increased plastic limit, the result is considered beneficial because the water content needed to change the clay to a plastic state has been raised. This dries up the clay, and greatly improves its workability. Calcium hydroxide, magnesium oxide, and magnesium hydroxide show this effect (Table 2). Calcium hydroxide seems to be the most effective of the three compounds for reducing soil plasticity. Magnesium oxide give a moderate increase of plastic limit, but the increase due to the addition of magnesium hydroxide is practically insignificant.

Results obtained from the study of pure compounds coincide with the theory of lime modification of clays (3, 4). That theory states that both a high pH and the presence of polyvalent cations are required to cause the change of clay texture by flocculation. The best results are obtained with a compound having a higher pH, for example, calcium hydroxide. The pH of calcium carbonate is near neutral. Magnesium oxide gives better results than magnesium hydroxide probably because of the slightly higher pH, which, in turn, is caused by a relatively higher solubility.

Effects of Commercial Limes. The results of plasticity tests on the natural soil and the various commercial limes and soil mixtures are shown in figure 1. The shape of the curves is characteristic of montmorillonite clay soils treated with lime: the liquid limit gradually decreases when the lime content is increased, and the plastic limit increases with increase in lime up to a certain point. At that point further increases in amount of additive do not further affect the plastic limit.

The plastic limit curves in Figure 1 show that the effectiveness of different commercial limes in raising plastic limits of a soil is very nearly the same. Because the chemical compositions are more consistent, high-calcium limes are especially close in performance. The maximum difference is only 4 percent moisture content, which occurs at 6% lime. Considering the method of Atterberg limits tests and the difficulties in field controls, this difference does not have much practical significance.

The dolomitic monohydrate limes are similar, although the spread of difference among all the limes is 6 percent in moisture

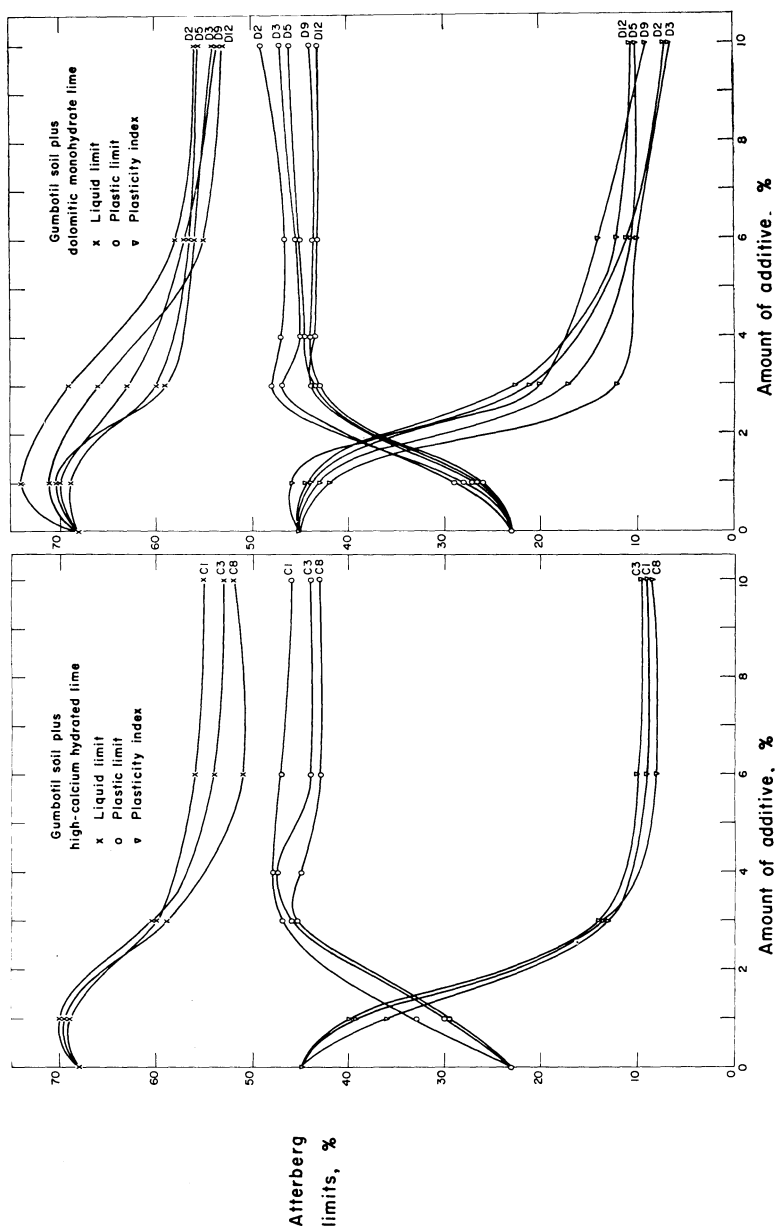


Figure 1. Effect of various commercial high-calcium and dolomitic limes on the Atterberg Limits of gumbotil.

content. The somewhat wider spread may be attributed to the more diversified chemical compositions of most dolomitic monohydrate limes. That it, further investigation showed that all the

so-called dolomitic monohydrate limes used were not true monohydrates. Based on X-ray diffraction analyses (Appendix A), as much as 88% and 86% of the magnesium oxide in limes D 9 and D 12, respectively, had been hydrated into magnesium hydroxide; and limes D 3, D 2, and D 5 were hydrated 66, 65 and 54% respectively. A qualitative picture of the chemical compositions of each dolomitic "monohydrate" lime is shown in Figure 2 by utilizing X-ray diffraction tracings.

It is further noted in Figure 2 that in addition to the large amount of magnesium hydroxide present, lime D 12 also contains a large amount of calcium carbonate. Since both calcium

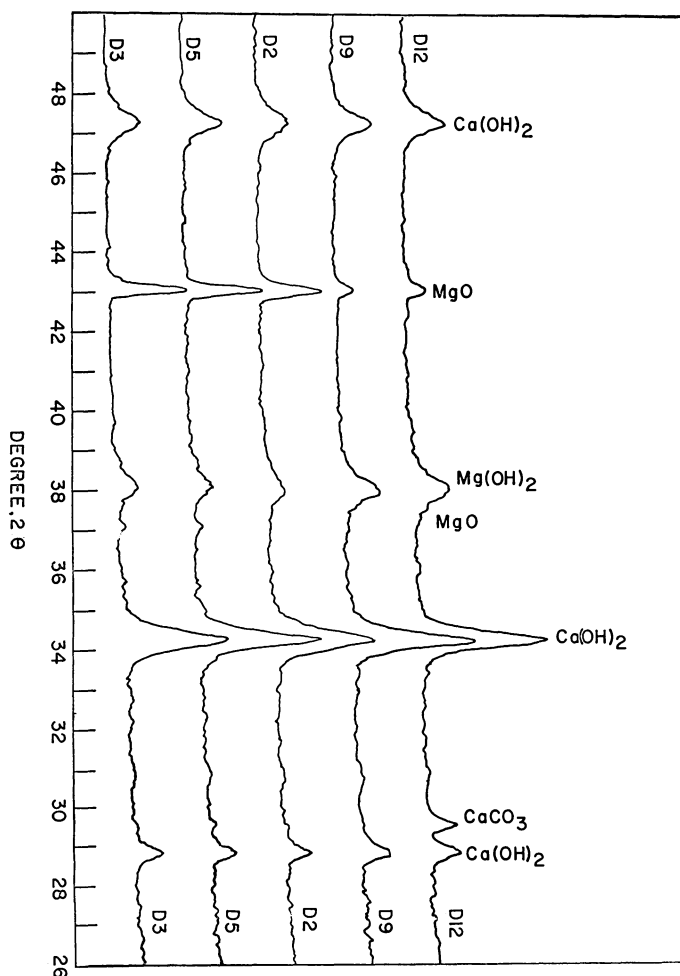


Figure 2.

carbonate and magnesium hydroxide are not beneficial in reducing soil plasticity, limes with large amounts of such compounds could conceivably result a loss in efficiency. The plastic limit curves in Figure 1, however, do not clearly show such a tendency.

Even more interesting is that there is practically no difference between high-calcium hydrated and dolomitic monohydrate limes for reducing soil plasticity. This may be because the amount of calcium hydroxide present in any type of lime has already met the ion saturation needs for this particular purpose.

### CONCLUSIONS

1. There is practically no difference between different types or between the same types of hydrated limes for reducing soil plasticity, though those limes may show significant difference in strength production characteristics.

2. The choice of hydrated limes for soil-lime stabilization should, therefore, be dictated by the relative price and strength characteristics of the lime.

3. In hydrated limes calcium hydroxide is the main component needed for modifying soil plasticity. Magnesium oxide shows a moderate effect, but magnesium hydroxide and calcium carbonate show practically no effect.

### APPENDIX A

Quantitative Determination of  $\text{Mg}(\text{OH})_2$  in Lime by X-ray Diffraction. A G.E. XRD-5 X-ray diffraction unit with a copper tube was operated at 40 Kvp and 20 ma. The radiation was nickel filtered. Proper intensity and resolution of the diffraction peaks were obtained by using an optical system consisting of a  $1^\circ$  beam slit, medium resolution Soller slit, and  $0.2^\circ$  detector slit. A time constant of 3 seconds, a scanning rate of  $0.2^\circ$   $2\theta$  per minute, and a chart speed of 1 in. per minute were used to reduce pen jiggle and give good reproducibility.

All samples of lime were pressed in disc-shaped sample holders made of brass so that they could be rotated during analysis to avoid effects of preferred orientation and to increase statistical accuracy.

The quantity of diffracting material affects peak height or area of a diffraction line. In this study the determinations were made by measuring the peak areas because they were more reproducible. The process is essentially one of scanning over a peak desired to obtain a total count for the diffracted peak and background. The area count is thus obtained by subtracting from the total count the background count. The background



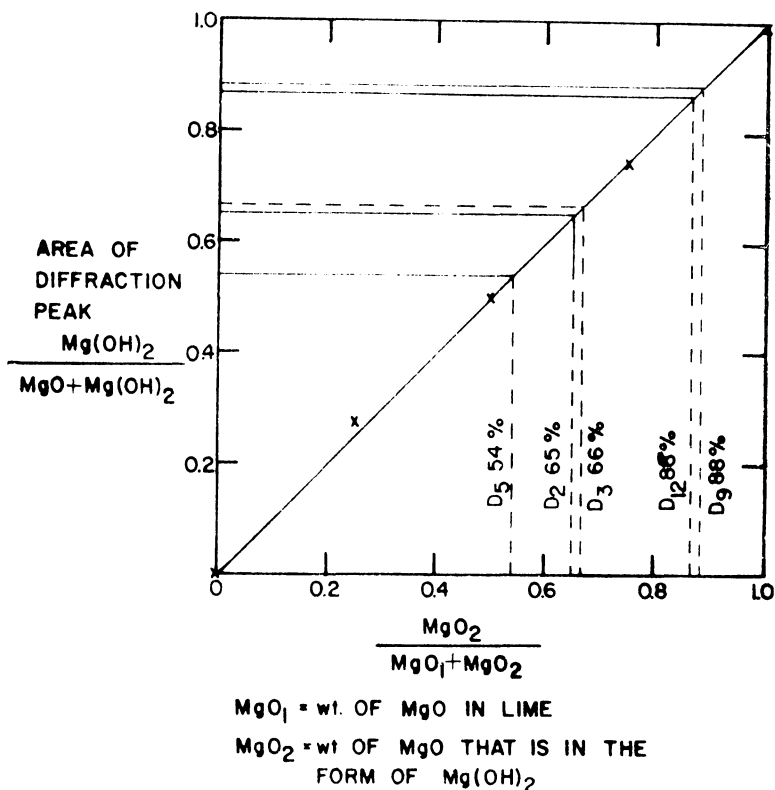


Figure 3. Relationship between the peak areas and the amount of  $\text{Mg(OH)}_2$  in commercial dolomitic monohydrate limes.

count is conducted at the end of the total count over the same period of time that total count requires.

The  $\text{MgO}(200)$  line at  $42.9^\circ 2\theta$  and the  $\text{Mg(OH)}_2(101)$  line at  $28.0^\circ 2\theta$  were used for the area measurements. It was found that 100 seconds counting time is sufficient to scan over an entire peak and end at a point of clear background. For the  $\text{Mg(OH)}_2(101)$  peak, the scanning starts at  $36.4^\circ 2\theta$ . After 100 seconds when scanning reached  $39.8^\circ 2\theta$ , a total count is obtained. Scanning is stopped at that point. Another 100 seconds is given to count the background. For the  $\text{MgO}(200)$  peak, scanning starts at  $41.0^\circ 2\theta$  and ceases at  $44.4^\circ 2\theta$ . Background count is then obtained at  $44.4^\circ 2\theta$ . All counts were repeated five times, and an average was taken.

A correction must be made, however, for the area counts obtained for  $\text{Mg(OH)}_2(101)$  peak, because between the range of  $36.4^\circ$  and  $39.8^\circ 2\theta$  there is also a  $\text{MgO}(111)$  peak present at  $37.0^\circ 2\theta$ . The  $\text{MgO}(111)$  peak is one-tenth of the intensity of

MgO(200) peak. The correction is made by subtracting one-tenth of the area count of MgO(200) from the area count obtained for  $\text{Mg}(\text{OH})_2$  (101). The value left is the true area count for  $\text{Mg}(\text{OH})_2$  (101).

Synthetic dolomitic monohydrate limes of varying proportions of MgO and  $\text{Mg}(\text{OH})_2$  were made to construct a standard calibration curve. A true dolomitic monohydrate is synthesized with a composition of 35% MgO and 65%  $\text{Ca}(\text{OH})_2$  by weight, which is the average composition of most commercially produced dolomitic "monohydrate" limes, disregarding the impurities usually present. Other synthetic limes were then made by substituting MgO with equivalent moles of  $\text{Mg}(\text{OH})_2$ . The peak areas of MgO(200) and  $\text{Mg}(\text{OH})_2$ (101) in each mixture were then determined. Figure 3 presents the relationship between the peak areas and the amount of  $\text{Mg}(\text{OH})_2$  present. Quantitative determination of  $\text{Mg}(\text{OH})_2$  in commercial dolomitic "monohydrate" limes are easily read from the curve once the diffraction areas are measured.

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